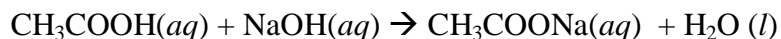
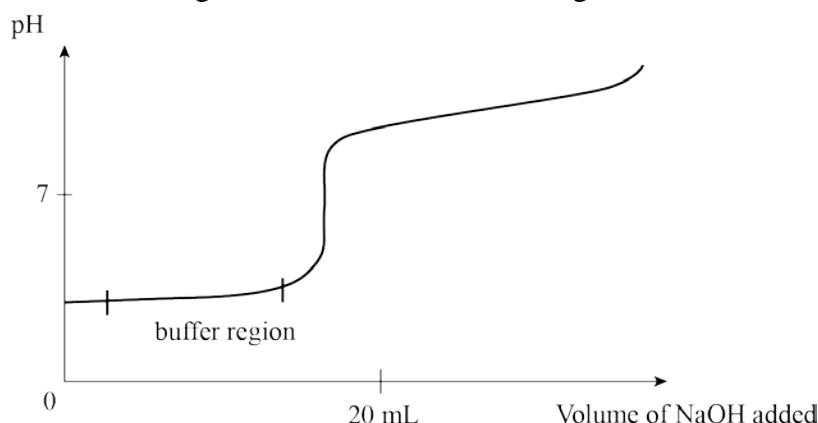


Acid Base Titrations

1) 20.00 mL of 0.125 mol L⁻¹ ethanoic acid is titrated with 0.125 mol L⁻¹ sodium hydroxide solution. The equation for this reaction is:



The titration curve for the reaction is given below and the buffer region is marked on the graph.



a) i) Explain why the solution in the titration flask can act as a buffer in this marked region. Use an equation in your answer.

ii) Put an **X** on the graph to show at which point the buffering action is the most efficient. Give reasons for your answer.

b) i) Show that the pH at the equivalence point for this titration is 8.78.

$$\text{p}K_{\text{a}}(\text{CH}_3\text{COOH}) = 9.24$$

ii) Explain why methyl orange is not a suitable indicator for this titration and why phenolphthalein is a suitable indicator for this titration.

Indicator	pK _a
Methyl orange	3.70
Phenolphthalein	9.30

iii) Phenolphthalein is an acid-base indicator. It is a weak acid and its formula can be represented as HIn. Phenolphthalein is colourless in acidic solutions and purple in basic solutions.

$$pK_a(\text{HIn}) = 9.60$$

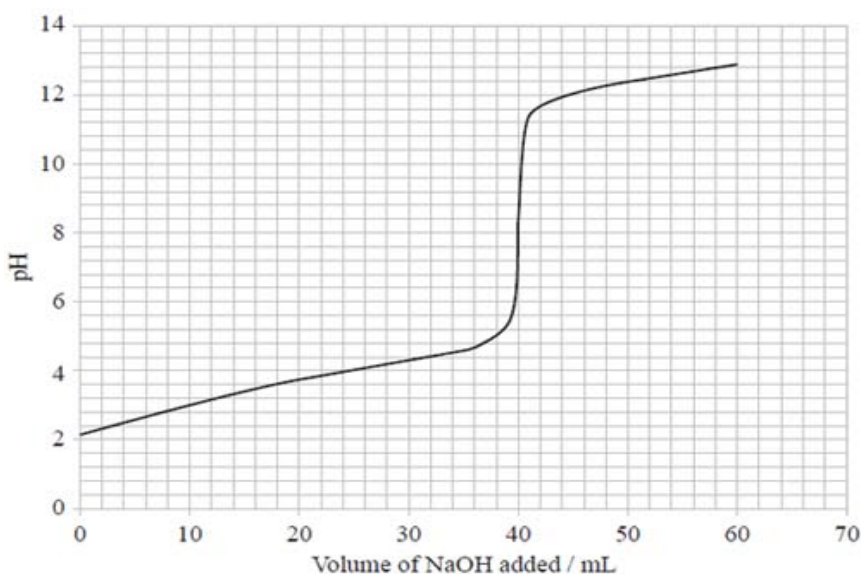
Discuss the effect of adding ethanoic acid and sodium hydroxide in turn to a solution containing phenolphthalein. In your answer, you should refer to:

- equilibrium principles
- the species responsible for the colours seen
- the pH range within which this indicator is effective.

2) A titration was carried out with methanoic acid and sodium hydroxide.

The equation for the reaction is: $\text{HCOOH} + \text{NaOH} \rightarrow \text{HCOONa} + \text{H}_2\text{O}$ $pK_a(\text{HCOOH}) = 3.74$

The curve for this titration is given below:



25.0 mL of methanoic acid solution is titrated with 0.180 mol L^{-1} sodium hydroxide.

a) i) Show that the concentration of the HCOOH solution is 0.288 mol L^{-1} .

ii) Calculate the initial pH of the 0.288 mol L^{-1} HCOOH solution.

b) Discuss the pH of the reaction mixture, in terms of the species present, after 20 mL of NaOH has been added. *No calculations are necessary.*

c) Some indicators and their pK_a values are shown in the table below.

Indicator	pK_a
Bromocresol green	4.7
Cresol red	8.3
Alizarin yellow	11.0

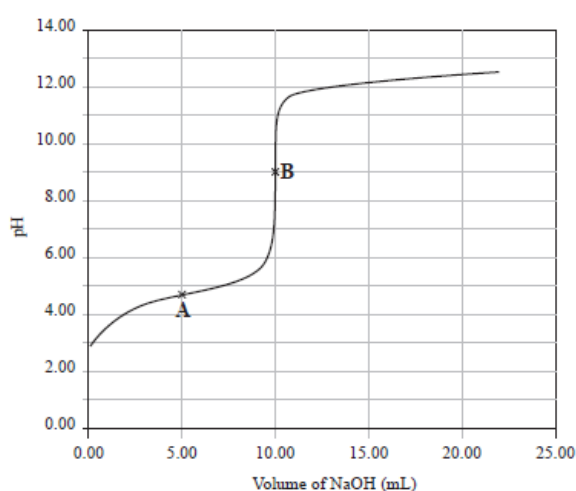
Discuss the suitability of **each** of these indicators for this titration.

In your answer you should include:

- an identification of the most suitable indicator(s)
- the consequences of choosing an unsuitable indicator
- an explanation of the significance of the pK_a in selecting an indicator.

3) Below is the titration curve for 10.0 mL of 0.100 mol L^{-1} ethanoic acid being titrated with 0.100 mol L^{-1} sodium hydroxide. Ethanoic acid can be represented by the symbol HET.

Titration of 0.100 mol L^{-1} ethanoic acid, HET, with 0.100 mol L^{-1} NaOH



a) With reference to the point marked **A** on the graph, discuss:

- the species present, and their relative concentrations
- an estimate of the pK_a value for ethanoic acid
- the effect of adding small amounts of strong acid or strong base to the solution.

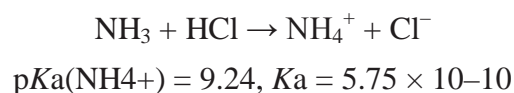
Include relevant equations in your answer. No calculations are necessary.

b) With reference to the point marked **B** on the graph, discuss the species present, and their effect on the pH at the equivalence point.

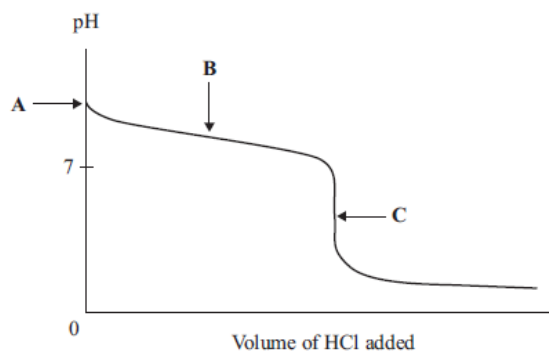
Include relevant equations in your answer. No calculations are necessary.

4) 20.00 mL of 0.160 mol L⁻¹ ammonia is titrated with 0.230 mol L⁻¹ hydrochloric acid.

The equation for the reaction is



The curve for this titration is given below.

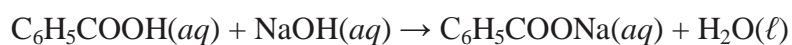


a) Explain, in terms of species present, why the pH at **B** (half way to the equivalence volume) is 9.24.

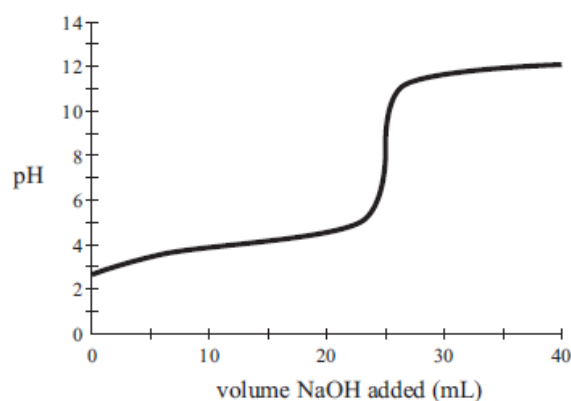
b) Calculate the pH at point **A**.

c) Discuss the pH of the reaction mixture at point **C**, in terms of the species present.

5) 25.0 mL of 0.0500 mol L⁻¹ benzoic acid solution (C₆H₅COOH) is titrated with 0.0500 mol L⁻¹ sodium hydroxide solution. The equation for the reaction is:



The titration curve for the reaction is:



a) Write the formulae of the four chemical species, apart from water and H₃O⁺, that are present at the equivalence point.

b) Explain why the solution in the titration flask has buffering properties after 9.80 mL of the NaOH solution has been added, but not when 25.0 mL has been added.

c) Some indicators are shown in the table below.

Indicator	pK_a
Methyl orange	3.70
Thymol blue	8.90
Phenolphthalein	9.30

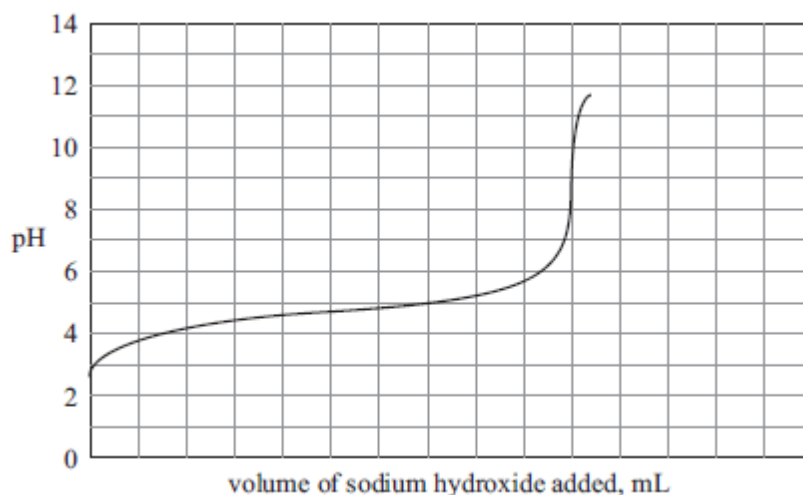
Discuss the suitability of these indicators for this titration.

Your discussion should include:

- identification of the most suitable indicator(s)
- consideration of how indicators are chosen for a titration
- the consequences of choosing an unsuitable indicator.

6) The following titration curve shows the addition of aqueous 0.100 mol L^{-1} sodium hydroxide to a solution of hydrazoic acid, HN_3 .

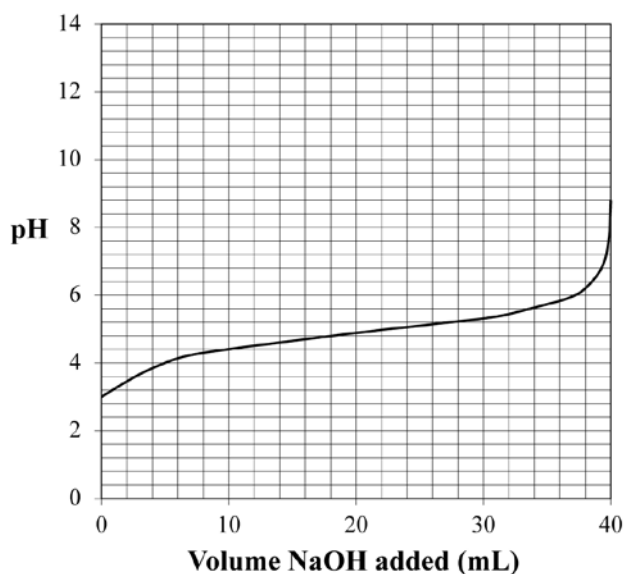
$$pK_a(\text{HN}_3) = 4.72$$



- a) i)** Draw a cross (X) on the titration curve to indicate the pH at the equivalence point of the titration.
- ii)** Complete the titration curve to show how the pH changes as more aqueous sodium hydroxide is added.
- b)** The initial pH of the hydrazoic acid (HN_3) is 2.6. Calculate the concentration of the HN_3 solution used in the titration.

7) A 0.160 mol L^{-1} solution of sodium hydroxide is titrated against 50 mL of aqueous propanoic acid, HPr. 40 mL of the sodium hydroxide solution was required to exactly react with the propanoic acid.

The reaction occurring can be represented as: $\text{HPr}(aq) + \text{NaOH}(aq) \rightarrow \text{NaPr}(aq) + \text{H}_2\text{O}$
 $K_a(\text{HPr}) = 1.35 \times 10^{-5}$



a) i) Show that the concentration of the aqueous propanoic acid is 0.128 mol L^{-1} .

ii) Calculate the pH of the aqueous propanoic acid.

b) Calculate the pH at the equivalence point.

c) 35 mL of the sodium hydroxide solution is added to a second 50 mL sample of the same acid to form a buffer solution.

i) What is the function of a buffer?

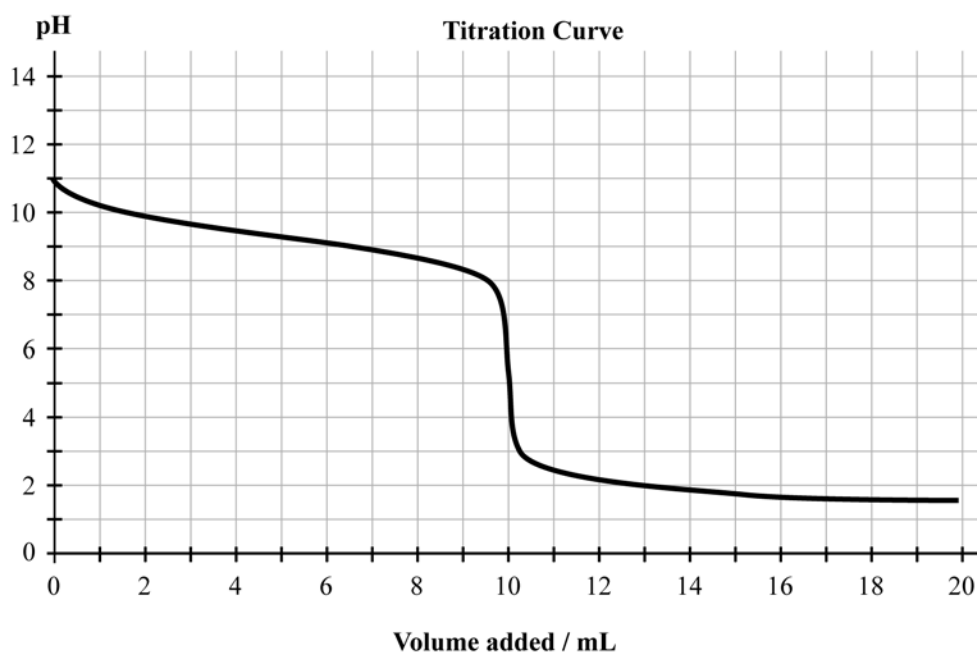
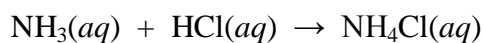
ii) Discuss the ability of the solution formed to act as a buffer. Your answer should include relevant equations.

d) The equivalence point of the titration could also be found using an acid-base indicator. Which of the following indicators would be suitable to use? Explain your choice of indicator.

Indicator	p <i>K</i> _a
Methyl orange	3.7
Bromocresol green	4.7
Methyl red	5.0
Thymol blue	8.9
Phenolphthalein	9.3

8) The graph below shows the change in pH when 40.0 mL of 0.0500 mol L⁻¹ aqueous NH₃ is titrated with 0.200 mol L⁻¹ aqueous HCl.

The equation for the reaction occurring during the titration is:



a) Use the curve to determine p*K*_a(NH₄⁺) and hence calculate *K*_a(NH₄⁺).

b) Explain why the pH at the equivalence point for this titration is less than 7. (Include an equation to support your answer.)

A $\text{NH}_4^+/\text{NH}_3$ buffer solution is prepared with a pH of 9.6.

c) Use the graph to describe how this buffer solution could be made from $0.0500 \text{ mol L}^{-1} \text{NH}_3$ solution and $0.200 \text{ mol L}^{-1} \text{HCl}$ solutions.

A second titration is carried out – this time 40.0 mL of $0.0500 \text{ mol L}^{-1} \text{NH}_4\text{Cl}$ solution is titrated against $0.200 \text{ mol L}^{-1} \text{NaOH}$ solution.

d) Write an equation for the titration reaction.

e) i) Show that $[\text{NH}_3]$ at the equivalence point is $0.0400 \text{ mol L}^{-1}$.

ii) Using $K_a(\text{NH}_4^+)$ determined in part (a) on the previous page, determine the pH at the equivalence point of the second titration.

9) The active ingredient in many sunscreens is *para*-aminobenzoic acid. It is a weak monoprotic acid and can be represented as HPab, while its conjugate base is Pab $^-$.

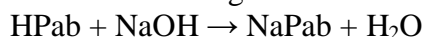
a) Write an equation for the reactions occurring at equilibrium when HPab is dissolved in water.

b) Write the expression for $K_a(\text{HPab})$.

A solution of HPab in water was prepared at 25°C and its pH was found to be 3.22.

c) Calculate the concentration of H_3O^+ in the solution.

d) The concentration of the HPab solution was determined by titration. A 20.0 mL sample of the HPab solution required 12.0 mL of $0.0500 \text{ mol L}^{-1} \text{NaOH}$ to reach the equivalence point. The equation for the reaction occurring is



i) Calculate the concentration of the HPab solution.

ii) Using the results from parts (c) and (d)(i), show that $\text{p}K_a(\text{HPab}) = 4.92$.

e) Would the pH at the equivalence point of the titration of HPab with NaOH be more than 7, less than 7 or equal to 7? Give reasons and include any relevant equations that support your answer.

f) Using the information above, sketch a curve showing the change in pH against the volume of sodium hydroxide added to the 20.0 mL HPab solution in the flask.

